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Effect of buffer thickness on properties of $In_{0.8}Ga_{0.2}As$/InP with two-step growth technique

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ABSTRACT

$In_{0.8}Ga_{0.2}As$ was grown by low-pressure metalorganic chemical vapor deposition (LP-MOCVD) on InP(1 0 0) substrate with two-step growth technique. Effect of buffer thickness on crystalline quality, surface morphology, electrical property and stress of $In_{0.8}Ga_{0.2}As$ epilayer was analyzed, and properties of the $In_{0.8}Ga_{0.2}As$ epilayer were characterized by X-ray diffraction, scanning electron microscopy, Hall measurements and Raman scattering. The experiments showed that the properties of the $In_{0.8}Ga_{0.2}As$ epilayer had close relation to the buffer thickness and the optimum buffer thickness was about 100 nm.

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1. Introduction

In recent years, there are great needs for 1–3 μm infrared detector, and the most important applications are space imaging (such as earth observation, remote sensing, environmental monitoring, etc. [1]) and spectroscopy. $In_xGa_{1-x}As$ material is very important for short-wavelength infrared detector. One of goals of growing the $In_{0.8}Ga_{0.2}As$ is an extension of response wavelength of the infrared detector. However, a large lattice mismatch between epilayer and substrate results in poor material quality. In order to overcome the limitation, many schemes [2–5] have been developed. Some authors choose a buffer layer that is linearly graded or step-graded in composition, even further by introducing strained superlattice structures in the buffer layer, inhibiting the dislocations to propagate towards the active layer grown on top of the buffer layer. Two-step growth technique is adopted in growth of mismatched heteroepitaxy layer, which low-temperature growth of the buffer layer is followed by annealing and growth of the epilayer at higher temperature [6]. The low-temperature buffer layer is believed to act as a template for succeeding high-temperature epilayer and to accommodate lattice strain caused by both lattice misfit and thermal mismatch. SiGe, AlGaN, InAs and GaN with two-step growth techniques [7–10] have been studied. In two-step growth technique, the buffer layer is an important issue and an actively investigated subject. We have reported the effects of In content of the buffer layer [11] and buffer growth temperature [12] on $In_{0.82}Ga_{0.18}As$ epilayer. However, the effect of buffer thickness on InGaAs epilayer with this technique is rarely studied. In this paper, we report the growth of $In_{0.8}Ga_{0.2}As$ on InP substrate with the two-step growth technique by low-pressure metalorganic chemical vapor deposition (LP-MOCVD) and the effect of buffer thickness on properties of $In_{0.8}Ga_{0.2}As$ epilayer.

2. Experiment

All samples were grown on semi-insulating InP(1 0 0) substrate by LP-MOCVD. The growth was performed using trimethylindium (TMI), trimethylgallium (TMG) and 10% arsine (AsH_3) in H_2 as precursors. Palladium-diffused hydrogen was used as carrier gas. The substrate on a graphite susceptor was heated by inductively coupling radio frequency power, the temperature was detected by a thermocouple, and the reactor pressure was kept 10,000 Pa. The thickness of $In_{0.8}Ga_{0.2}As$ buffer layer was varied from 10 nm to 200 nm and the growth temperature was fixed at 450 °C. However, the $In_{0.8}Ga_{0.2}As$ epilayer was grown at 530 °C and the thickness was fixed 0.8 μm. The sample with 10 nm, 50 nm, 100 nm, and 200 nm thick buffer layer was named to A, B, C, and D, respectively. The composition of InGaAs was estimated from X-ray diffraction (XRD) peak of the alloy using Vegard's law [13]. The properties of the $In_{0.8}Ga_{0.2}As$ epilayer were characterized by XRD, scanning electron microscopy (SEM), Hall measurements and Raman scattering. The electrical property of epilayer was investigated by Hall measurements using van der Pauw technique at room temperature. The Raman measurement was performed at room

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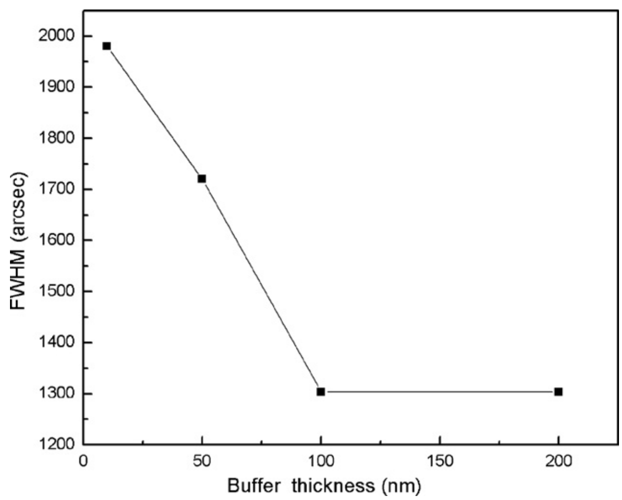

Fig. 1. Dependence of FWHM of X-ray diffraction of the samples on the buffer thickness.

temperature in backscattering geometry, in which the 514 nm line of an Ar^+ laser was used for the exciting light.

3. Result and discussion

3.1. X-ray diffraction

Crystalline quality is essential for semiconductor materials, which influences the device performance. The results of XRD measurement are shown in Fig. 1. For sample A, its buffer thickness is 10 nm, full-width at half-maximum (FWHM) of XRD is 1980 s. This value is the widest in four samples, meant its crystalline quality is the worst. The FWHM is 1720 s when the buffer thickness is 50 nm. It indicates the crystalline quality of sample B is improved. However, the FWHM reaches a minimum of 1303 s when the thickness of the buffer layer is 100 nm, shows that the crystalline quality of sample C is better than those of samples A and B. For sample D, the FWHM is the same as that of sample C. From the XRD results, it can be concluded that the crystalline quality of epilayer is improved by introducing a proper buffer thickness. D'Hondt et al. [14] have reported the $In_{0.82}Ga_{0.18}As$ grown on linearly graded InGaAs buffer layer, in which the FWHM of XRD was 1217 s for the buffer thickness of 1 μm, and it was 1353 s for the buffer thickness of 7 μm. The buffer layer with the linear graded technology is different from that with two-step growth technique and is quite thick layer, which gradually reduces or eliminates defects of InGaAs.

3.2. Scanning electron microscopy

Fig. 2(A)–(D) shows the surface morphology of the $In_{0.8}Ga_{0.2}As$ epilayer with different buffer thickness 10 nm, 50 nm, 100 nm, and 200 nm, respectively. According to the work of Matthews and Blakelsee [15], the epilayer is in the elastic strain when its thickness is smaller than a certain critical thickness, and it is in the plastic strain when its thickness is bigger than the critical thickness. In Gendry's experiments [16], $In_{0.82}Ga_{0.18}As$ was observed for growth at 450 °C, its critical thickness was 20.5 nm. However, $In_{0.82}Ga_{0.18}As$ was grown at 525 °C, its critical thickness was 11 nm. For sample A, the buffer thickness of 10 nm, the buffer layer is in the elastic strain. A surface with a cross-hatched patterns and some pits appear, indicating the buffer layer in the elastic strain not to be able to improve the surface morphology of the $In_{0.8}Ga_{0.2}As$ epilayer. For sample B, the buffer thickness of 50 nm, and the buffer is in plastic strain. It is observed that the cross-hatched patterns disappear, but the pits exist. Its surface morphology is obviously improved. For sample C, the buffer thickness of 100 nm, the cross-hatched patterns and the pits disappear, the surface of the $In_{0.8}Ga_{0.2}As$ epilayer becomes flat. It means that a suitable thickness of the buffer layer in the plastic strain is beneficial to improve surface morphology of the epilayer. For sample D, the buffer thickness of 200 nm, the surface morphology is similar to that of sample C, but some pits appear

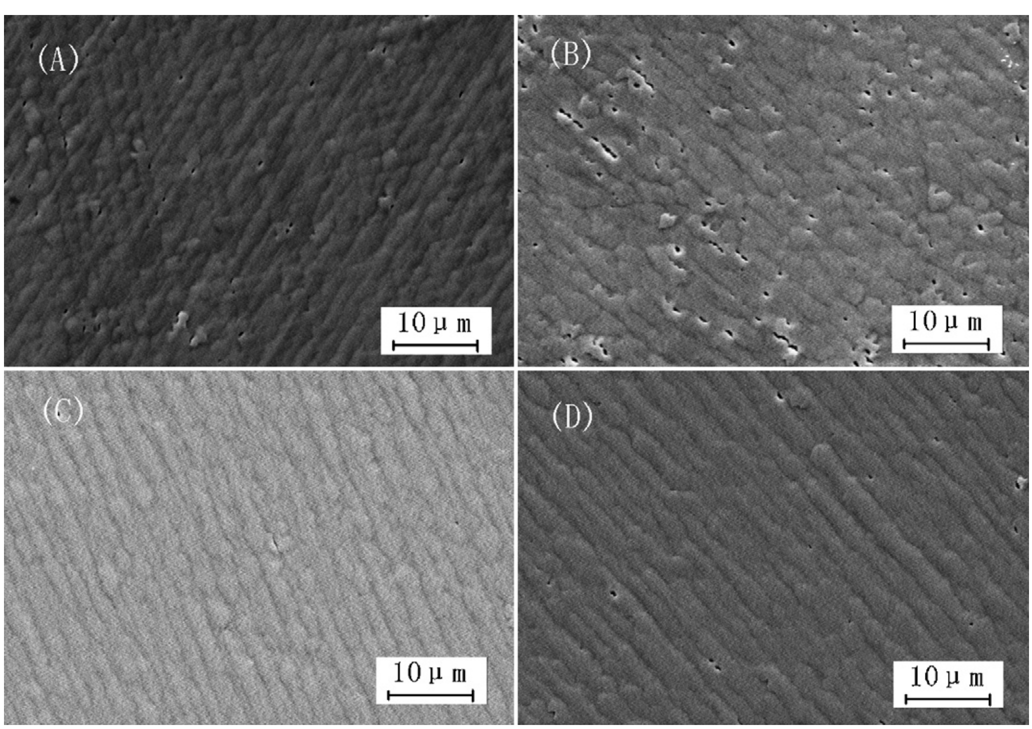

Fig. 2. SEM surface morphology of a 0.8 μm $In_{0.8}Ga_{0.2}As$ grown on a buffer with thickness (A) 10 nm, (B) 50 nm, (C) 100 nm, and (D) 200 nm, respectively.

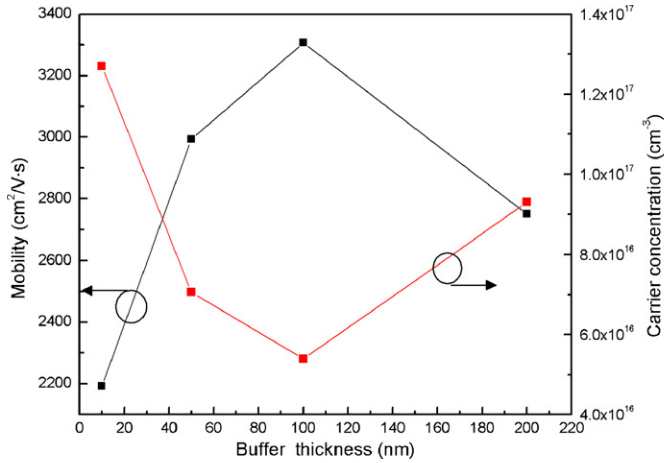

Fig. 3. Variation of mobility and carrier concentration of the $In_{0.8}Ga_{0.2}As$ epilayers with buffer thickness.

again. It indicates that the surface morphology is degraded, because the thick buffer layer is close to the epilayer and is not helpful to improve the surface morphology.

3.3. Hall measurements

The electrical property of the $In_{0.8}Ga_{0.2}As$ epilayer is measured with magnetic field of 2100 G at room temperature. In electrode sintering is performed at 380 °C for 10 min. The results of Hall measurements are shown in Fig. 3. On the one hand, mobility increases from 2193 $cm^2/V\,s$ to 3308 $cm^2/V\,s$ with the buffer thickness from 10 nm to 100 nm, and it decreases from 3308 $cm^2/V\,s$ to 2751 $cm^2/V\,s$ with the buffer thickness from 100 nm to 200 nm. On the other hand, carrier concentration decreases from $1.27 \times 10^{17}\,cm^{-3}$ to $5.39 \times 10^{16}\,cm^{-3}$ with the buffer thickness from 10 nm to 100 nm, and it increases from $5.39 \times 10^{16}\,cm^{-3}$ to $9.30 \times 10^{16}\,cm^{-3}$ with the buffer thickness from 100 nm to 200 nm. In the experiments, the growth conditions, such as V/III ratio, growth temperature, and pressure are fixed, but only the thickness of buffer layer is different. It is reasonable to speculate that the changes of the mobility, and the carrier concentration of the $In_{0.8}Ga_{0.2}As$ epilayer are related to the buffer thickness. Defects of the $In_{0.8}Ga_{0.2}As$ epilayer are decreased because of introducing optimum buffer thickness. The defects caused by the lattice mismatch will serve as scattering centers for electrons and limit the mobility. The carrier concentration is decreased with the improvement of the crystalline quality of the $In_{0.8}Ga_{0.2}As$ epilayer.

3.4. Raman scattering

Fig. 4 shows the Raman spectra of the four samples. There are two Raman peaks in each spectrum, which are around 234 cm^{-1} and 254 cm^{-1}, corresponding to longitudinal optical (LO) phonon modes of InAs and GaAs, respectively. The evaluations of the stress of the $In_{0.8}Ga_{0.2}As$ epilayer are made from a frequency shift of the GaAs-like LO phonon. The inset of Fig. 4 shows the dependence of the $\Delta\Omega_{LO}$ of GaAs-like on the buffer thickness by the Raman scattering measurements. A least-squares calculation gives the following equation [17]:

$$\omega_0^{LO} = -32.4x^2 - 18.6x + 290.0 \quad (1)$$

where ω_0^{LO} is the GaAs LO phonon modes of bulk $In_xGa_{1-x}As$ in cm^{-1}, x is the content of In.

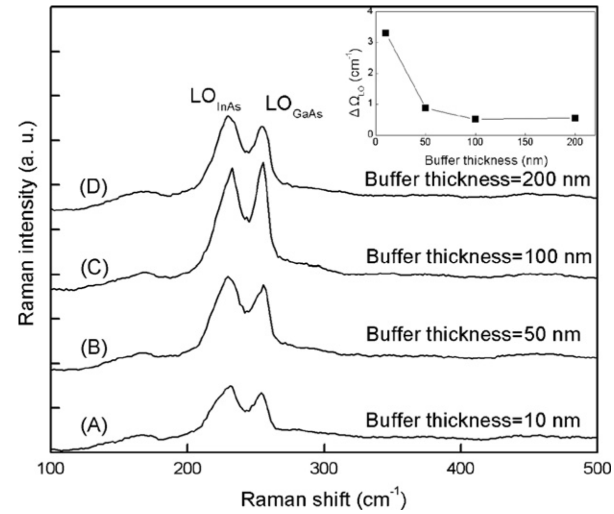

Fig. 4. Raman spectra of the samples with different buffer thickness, the inset shows the dependence of the $\Delta\Omega_{LO}$ of GaAs-like on the buffer thickness.

Since the compressive stress shifts phonon to high energy [18], the GaAs-like LO phonon frequency of the four samples has frequency shift. Following the formulas and definition [19], the stress F is expressed as

$$F = \frac{3\Delta\Omega_{LO}}{\omega_0} \Big/ \left[(s_{11} + 2s_{12})\frac{(p+2q)}{\omega_0^2} - (s_{11} - s_{12})\frac{(p-q)}{\omega_0^2} \right] \quad (2)$$

where $\Delta\Omega_{LO} = \Omega^{LO} - \omega_0^{LO}$, Ω^{LO} is the measured value of LO phonon mode, s_{11} and s_{12} are the elastic stiffness constants, p and q are the optical phonon deformation constants, and ω_0 is the frequency of the $k = 0$ optical phonon. By the linear interpolation from data [20] for InAs and GaAs, it can be obtained p, q, s_{11}, and s_{12} for $In_{0.8}Ga_{0.2}As$. Using the measured results $\Delta\Omega_{LO}$ and Eq. (2), it can be obtained that the stress of the $In_{0.8}Ga_{0.2}As$ epilayer is −9.63 GPa, −2.56 GPa, −1.50 GPa, and −1.62 GPa, corresponds to the sample A, B, C, and D, respectively. The stress in epilayer mainly caused by the lattice mismatch between the epilayer and substrate, it is decreased with increasing buffer thickness, and it reaches to a minimum when the buffer thickness is 100 nm. The results show that the stress of the $In_{0.8}Ga_{0.2}As$ epilayer is dependent on its buffer thickness.

4. Conclusions

In summary, $In_{0.8}Ga_{0.2}As$ was grown by LP-MOCVD on InP substrate with two-step growth technique. Based on the XRD results, the crystalline quality of epilayer showed an obvious improvement when the buffer thickness was 100 nm. From the results of the SEM, the surface morphology of epilayer was effectively improved by introducing an appropriate buffer thickness. According to the results of Hall measurements and Raman scattering, the electrical property of the epilayer was optimum and the stress of the epilayer reached to a minimum when using a certain buffer thickness. The optimum thickness of buffer was about 100 nm.

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